

EXPERIMENTAL STUDY FOR EVALUATING THE SEISMIC PERFORMANCE OF RC FRAME STRUCTURE WITH PARTIALLY INFILLED BY BRICK MASONRY

*Jafril Tanjung¹, Febrin Anas Ismail¹, Maidiawati², Oscar Fithrah Nur¹ and Mahlil³

¹Engineering Faculty, Andalas University, Indonesia, ²Padang Institute of Technology, Indonesia; ³Syiah Kuala University, Indonesia

*Corresponding Author, Received: 13 Dec. 2018, Revised: 30 Dec. 2018, Accepted: 15 Jan. 2019

ABSTRACT: The responses of the brick masonry infilled reinforced concrete (RC) frame structures under seismic excitation were quite complex due to highly nonlinear of their composite behavior and interaction between RC frame structure and its brick masonry infill. The presence of the brick masonry infills can greatly improve the seismic performance of RC frame structures by increasing their lateral strength and stiffness, respectively. However, when the RC frame structure is only partially infilled with the brick masonry wall, the responses of the RC frame structure become completely different. In this study, a series of experiments was conducted to evaluate the seismic performance of RC frame structures with partially infilled by the brick masonry. Three of 1/4 scale RC frame specimens, i.e. a bare RC frame, a fully brick infilled RC frame and a partially brick infilled RC frame have been experimentally tested under lateral static reversed cyclic loading. Experimental results have shown that the existence of the partially brick masonry infilled in the RC frame structure plays a significant role in damaging of the RC column.

Keywords: RC building, Partial brick masonry, Seismic performance, Reversed cyclic loading

1. INTRODUCTION

The unreinforced burned clay brick masonry has been commonly used as the infills and/or partition walls in reinforced concrete (RC) frame structures in the seismic-prone area such as Sumatra Island, Indonesia. Post-earthquake observation after M8.5 and M7.9 Sumatra earthquake 2007 [1], M7.9 West-Sumatra earthquake 2009 [2] and M6.5 Pidie Jaya – Aceh earthquake 2016 [3] demonstrated the beneficial as well as the undesired effects of the brick masonry infill to the seismic performance of the RC frame structures. As it was investigated by Maidiawati and Sanada on the damaged of RC buildings after Sumatera earthquake 2007 [4] indicated that the significant contribution of the brick masonry infill helped the structure survive during the Sumatra earthquake 2007. Unfortunately, the brick masonry infills also caused the undesired effect on the seismic response of structures, such as soft-story effect. The similar and identical phenomenon mentioned above was also clearly observed after West-Sumatra and Pidie-Jaya earthquakes [5] as well as Wenchuan-China earthquake 2008 and Lushan-China earthquake 2013 [6].

Indeed, in recent decades, several research activities have been devoted to investigate how the effects of brick masonry infill to seismic performance of the RC frame structures. These research activities including the research work in

the field of experimental study and analytical study as well. Maidiawati, Sanada, Konishi and Tanjung [7] have tested the RC frame structures infilled by the exported brick masonry from survived-RC building in Padang city, Indonesia. The experimental studies have also been conducted by Tanjung and Maidiawati [8,9] using local brick masonry produced in West-Sumatra area. These experimental studies have concluded that the brick masonry infills increase the lateral strength and stiffness of the RC frame structure; delayed the failure of the structure; and unfortunately decrease the overall ductility of the structure. The presence of the brick masonry infills caused changes in the deformation behavior of structure, i.e. from initially follow the behavior of frame structure and thus changed to truss structure behavior. Others similar and comprehensive experimental researches have been well-documented by Al-Chaar [10]; Cavaleri and Trapani [11]; and Korkmaz and Taciroglu [12].

The studies of Cavaleri and Trapani [11]; and Maidiawati and Sanada [13] have been proposed the analytical method for describing the contribution of brick masonry infills to seismic performance of the RC frame structures. Their proposed methods were derived based on their experimental works. Cavaleri and Trapani applied the macro modeling approach by substituting the brick masonry infills with diagonal pin jointed struts. This approach has succeeded for simulating the nonlinear seismic responses of RC frame structure with brick masonry

infills subjected to lateral static reversed cyclic loading. In another method, Maidiawati and Sanada have proposed the analytical model by replacing the brick masonry infill with the diagonal compression strut. This diagonal compression strut, indeed, represents the idealization of distributed compression transferred between RC frame structure and brick masonry infill interfaces. In their method, the equivalent strut width is evaluated by static equilibriums of the compression balance and lateral displacement compatibility at the frame–infill interfaces. This proposed analytical method has also succeeded when evaluating the seismic performance of the survived RC building during the 2007 Sumatra earthquake.

The studies activities resumed above are mostly focused on the investigation of the effects of fully brick masonry infills in the RC frame structures. The studies for the partially brick masonry infills are still very limited. One of them has been performed and reported by Pradhan et.at. [14]. Others researchers' studies, such as by Kakaletsis et.at. [15]; Surendran and Kaushik [16]; and Akhoundi, Lourenco and Vasconcelos [17] are the studies in the field of the brick masonry infills with central, door or window openings.

Based on the post-earthquake investigation after Pidie-Jaya, Aceh earthquake 2016 [4] has shown the different damaged pattern of the RC frame structure with partially infilled by brick masonry compare to fully infilled by brick masonry and bare frame as well. The series experimental study discussing in this paper was conducted to find the answer how the partially brick masonry infilled in RC frame structure influences the seismic performance of it structures.

2. EXPERIMENTAL PROGRAM

The experimental works describe in this paper was conducted by using the structural testing facilities at Structural and Construction Material Laboratory, Syiah Kuala University, Banda Aceh, Indonesia. The materials for constructing the tested specimens were collected from local markets in Banda Aceh. Three of 1/4 reduce-scaled one-bay and one-story RC frame specimens were prepared, i.e. a bare RC frame, a fully brick infilled RC frame and a partially brick infilled RC frame. The specimens represent the first story of commonly constructed low-rise RC frame structures in Indonesia. All the specimens were subjected to lateral static reversed cyclic loading.

2.1 Test Specimens

The typical geometry and reinforcement details used for all RC frame specimens are illustrated in Fig.1. The columns of the RC frame were detailed

to yield in flexure before shear failure.

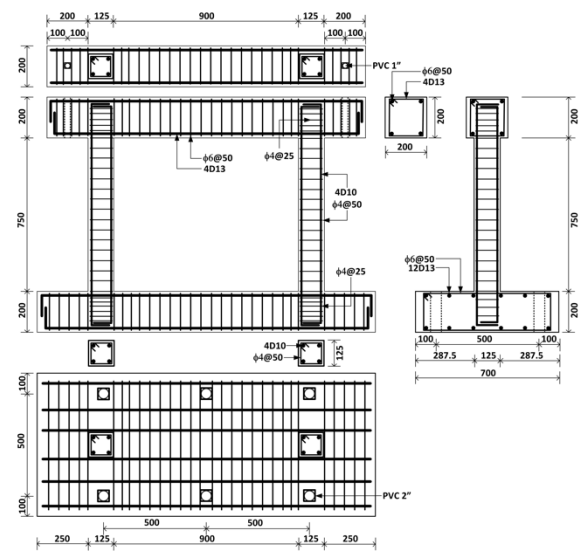


Fig. 1 Reinforcement Detail of Specimen.

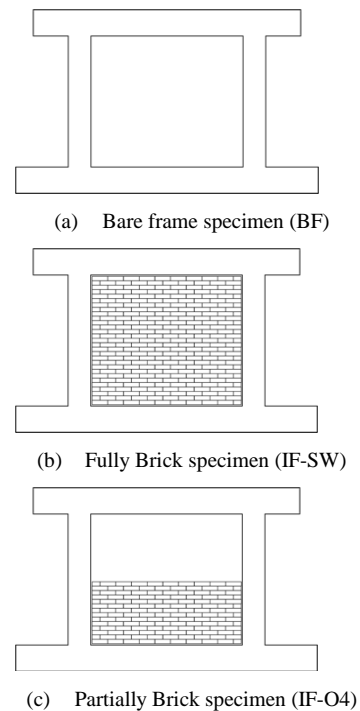


Fig. 2 Type of Specimens.

The dimension of the cross-section of columns was 125 mm x 125 mm and reinforced with 4D10 longitudinal bars and $\phi 4@50$ transverse hoops. The dimension of the cross-section of the columns and their reinforcements were designed considering the scale reduction. The clear height of the columns was 750 mm. The dimension of top-beam was 150 mm wide, 150 mm deep and 1550 mm long and reinforced with 4D13 longitudinal bars and $\phi 6@50$ transverse stirrups. The columns were then supported by the lower-beam which was fastened to

the strong floor by using six post-tensioning rods. The dimension of the lower-beam was 700 mm wide, 150 mm deep and 1650 mm long and reinforced with 12D16 longitudinal bars and $\phi 6@50$ transverse stirrups.

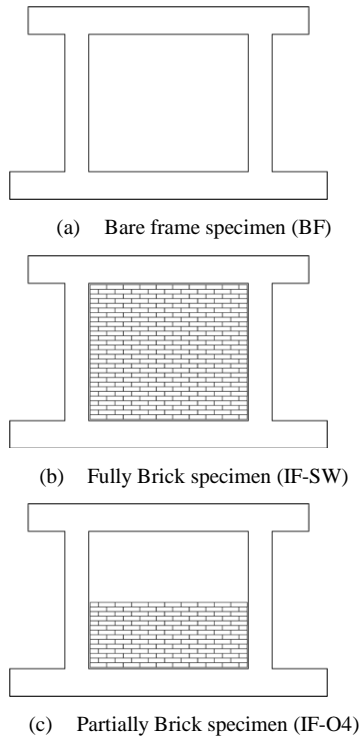


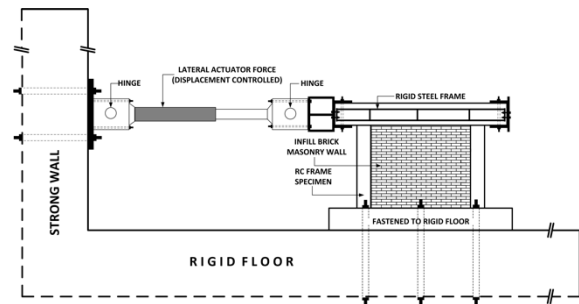
Fig. 2 Type of Specimens.

The schematic view of three RC frame specimens is shown in Fig. 2, i.e. the bare frame (BF) specimens, fully brick masonry infilled (IF-SW) specimen and partially brick masonry infilled (IF-O4) specimen. The infill area of IF-O4 specimen was approximately half of infill area of IF-SW specimen. The IF-SW and IF-O4 specimens were infilled by 1:4 reduce-scaled masonries of burnt clay brick with a dimension of 30 mm wide, 13 mm deep, 60 mm long. The mortar beds with the ratio of cement: water in 1:0.5 were used for assembling the brick masonry as infills. The infill was then covered by 5 mm thickness of mortar on it both surfaces. Noting that for all specimens, there were no shear connectors installed on the interface between column and infill.

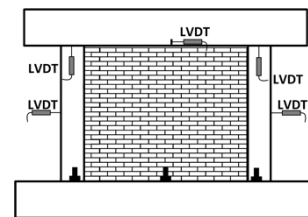
2.2 Test Setup and Instrumentation

Figure 3.a shows a schematic image of the cyclic loading test setup plan for current experimental works. At first, the specimen was placed on the rigid floor. To keep the specimen remain in its place, the lower-beam was fastened to the rigid floor by using six post-tensioning rods. A double action lateral actuator force equipment was attached and fastened to the strong wall by using

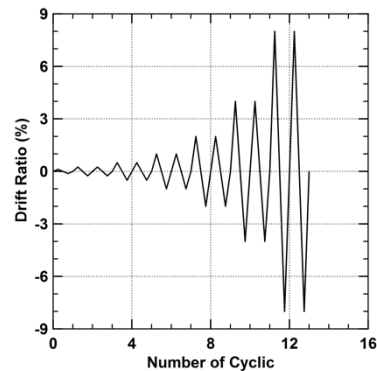
four post-tensioning rods.



(a) Cyclic Loading Test Setup



(b) LVDT Plan



(c) Cyclic Loading Procedure

Fig. 3 Test Setup and Instrumentation.

In order to prevent the applied force cause the out of plane deformation during testing, the top-beam was constrained by two horizontal steel beams. These two horizontal beams were connected to the actuator force, which mounted on the strong wall. The displacement transducers were installed at several points to measure the deformation as well as to be controlling the displacement point of the whole test, as shown in Fig. 3b.

The cyclic procedure applied in current works is following FEMA461 [18] as is given in Fig. 3c. The procedure began with a drift ratio of 0.125% ($R=1/800$), 0.250% ($R=1/400$), and up to 8% ($R=1/12.5$); where R is the drift angle. This cyclic procedure was conducted in displacement control with the loading speed of approximately 0.05 mm/s. Except for the first drift ratio, two cycles were applied for each drift ratio. Incremental of the applied lateral static load and the deformation of the specimen were monitored and recorded throughout the tests. In order to identify the failure mechanism

of the specimen, the initial cracks and its crack propagation were marked on the specimen in every loading cycle.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Material Properties

The material properties used for constructing RC frame specimens, including their brick masonry

loading-displacement for BF specimen. The ultimate lateral strength was reached at 51.3kN at 57.8 mm of lateral displacement, i.e. at the drift ratio of almost 8% ($R=1/12.5$). The initial flexural crack at the top side of the tensile column was observed within the drift ratio of 0.25% ($R=1/400$); the lateral displacement was 1.2 mm. The initial shear crack appeared at the compressive column within the drift ratio 0.5% ($R/200$); the lateral displacement at that time was 3.8 mm. Within the last cycle of drift ratio of 8% ($R=1/12.5$), the

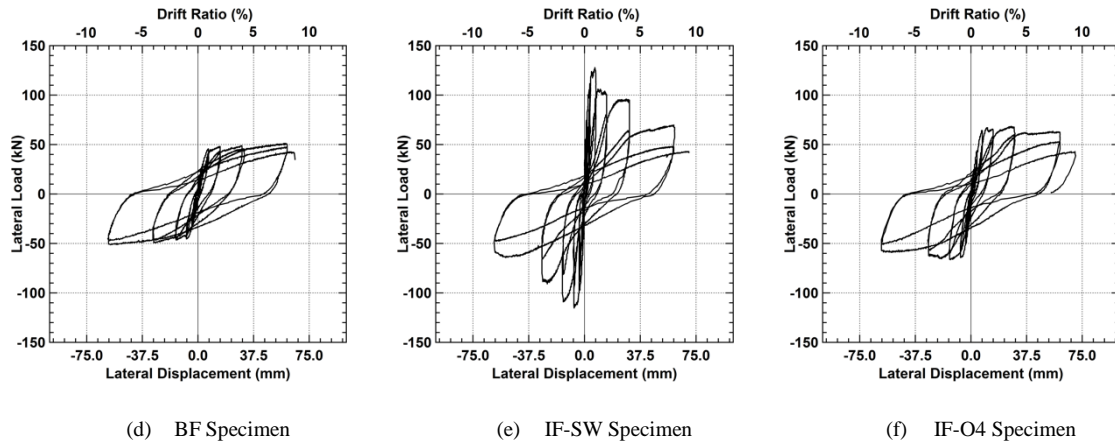


Fig. 4 Relation of Applied Lateral Loading and Displacement.

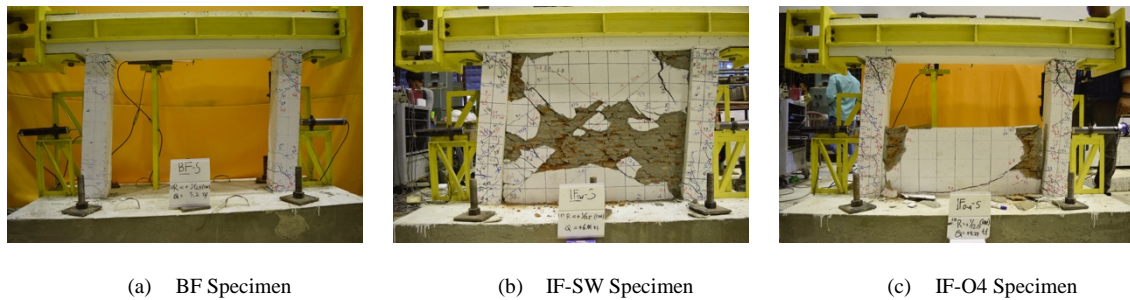


Fig. 5 Crack Patterns at Drift Ratio=8% ($R=1/12.5$).

infills, were obtained by standard material testing procedures. The compressive strength of concrete cylinder at 28 days after casting was 49.9 MPa, i.e. the sample of the concrete was cast to the RC frame specimens. The compressive strength of the brick masonry cube was 10.9 MPa. The nominal yield (tensile) strengths of the reinforcements, respectively for $\varnothing 4$, $\varnothing 6$, D10, and D13, were 390.2 (598.3) MPa, 346.8 (448.6) MPa, 462.0 (619.7) MPa, and 421,1 (582.4) MPa.

3.2 Loading-Deformation Curves and Crack Patterns

3.2.1 Bare-frame Specimen (BF)

Figure 4.a. shows the hysteretic loop of lateral

compressive column experienced shear failure at the lateral displacement of 57.8 mm, as is shown in Fig. 5.a. As we expected, the RC columns of the specimen exhibited the flexural failure before experienced the shear failure.

3.2.2 Fully Brick Masonry Infilled Specimen (IF-SW)

The hysteretic loop of the relation between the lateral loading and displacement for IF-SW specimen is shown in Fig. 4.b. Its figure exhibits that the presence of brick masonry infill in RC frame significantly increased the lateral stiffness of the specimen. The increasing of the lateral stiffness was indicated by increasing of the lateral strength capacity of the specimen, i.e. 127.7kN at about 7

mm lateral displacement. Increase about 2.5 times compare to the capacity of the bare-frame BF specimen.

A separation crack has appeared between column and brick masonry infill at the beginning of loading, i.e. within the drift ratio of 0.125% ($R=1/800$). Initial flexural and shear cracks of the tensile column were observed within the drift ratio of 0.25% ($R=1/400$) at the lateral displacement about 1.3 mm and 1.6 mm, respectively. The diagonal shear crack was observed at the center of brick masonry infill within the drift ratio 0.5% ($R=1/200$) when the lateral displacement about 3.4 mm. Within the drift ratio of 2% ($R=1/50$), the brick masonry infill experienced the shear failure, thus the lateral strength of the specimen started to significantly degradant. As soon as shear failure of the brick masonry infill, the strength of the specimen then now depends on the strength of the RC frame structure. Continued the lateral loading caused the boundary columns experienced the shear failure within the drift ratio of 8% ($R=1/12.5$) as is shown in Fig. 5.b.

3.3.3 Partially Brick Masonry Infilled Specimen (IF-OS)

For the IF-O4 specimen, the hysteretic loop of the lateral loading-displacement is shown in Fig. 4.c. The ultimate lateral strength of 68.5kN was reached at lateral displacement about 27.1 mm. Although the area of the brick masonry infill for IF-O4 specimen was half of IF-SW specimen, the increasing the lateral strength of IF-O4 specimen much less than IF-SW specimen, compare to bare specimen BF. The lateral strength of IF-SW specimen increased about 148%, while the IF-O4 specimen increased only about 33%.

The failure pattern of the brick masonry infill in this specimen was dominated by the horizontal crack. Compare to IF-SW specimen, i.e. the major failure pattern was inclined diagonal shear cracks. The presence of this partially brick masonry infill made the stiffness of the RC columns specimen, where the partially brick masonry installed, relatively increase when was compared to other parts of these columns. As the consequence, the parts of the columns without brick masonry infill became the weak area of the RC frame structure. The observation during experimental works has shown that the failure of the current specimen was dominated by the shear failure at the area of columns without brick masonry infill as is shown in Fig. 5.c. This fact suggested that the partially brick masonry infill in RC frame structure has significantly played role in the damaged of the RC

columns of the specimen.

4. CONCLUSION

The experimental work for evaluating the seismic performance of the partially brick masonry infilled RC frame structure has been conducted in this study. For this purpose, three of 1:4 reduce-scaled one-bay one-story RC frame specimens have been tested subjected to lateral static reversed cyclic loading, i.e. bare RC frame, fully brick infilled RC frame and partially brick infill specimens, respectively. When comparing the BF to IF-SW specimens, the presence of the fully brick masonry in IF-SW frame directly adding the stiffness of the RC frame; resulting the increased of the lateral strength capacity of the RC frame. The presence of this full brick masonry has also delayed the collapse of RC columns in the IF-SW specimen; since the RC frame and brick masonry now in the composite when they were subjected to lateral loads. Unfortunately, for the IF-O4 specimen, although its lateral strength capacity has increased, compared to BF specimen, the presence of partially brick masonry infill caused the premature collapse of the RC column of the specimen. Therefore, when the RC frame is planned to partially infilled by the brick masonry, the reinforcement design of the column has to consider the additional shear force caused by the presence of it partially brick infills.

5. ACKNOWLEDGMENTS

This research work is financially supported by the Institute of Research and Community Development of Andalas University through the Research Grand of Program Penelitian Skim Klaster Riset Percepatan Guru Besar (KRP2GB) with the contract number 13/UN.16.17/PPP.PGB/LPPM/2018. The authors also sincerely acknowledge to Professor Katsuki Takiguchi, Takiguchi Laboratory, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Japan; Dr. Abdullah, Civil Engineering Department, Syiah Kuala University; head and staffs of Structure and Construction Material Laboratory, Engineering Faculty, Syiah Kuala University, for supporting during prepared the specimens, provided the structural testing facilities and conducted the structural tests.

6. REFERENCES

- [1] https://en.wikipedia.org/wiki/September_2007_Sumatra_earthquakes.
- [2] https://en.wikipedia.org/wiki/2009_Sumatra_earthquakes.
- [3] https://en.wikipedia.org/wiki/2016_Aceh_earthquake.

- hquake.
- [4] Maidiawati and Sanada Y., Investigation and Analysis of Buildings Damaged during the September 2007 Sumatra, Indonesia Earthquakes, *Journal of Asian Architecture and Building Engineering (JAABE)*, Vol 7 No 2, 2008, pp. 371-378.
- [5] Tanjung J., Post-earthquake Investigation Report of Damaged Reinforced Concrete Buildings after Pidie-Jaya Earthquake 2016, Civil Engineering Department, Andalas University, Unpublished Report, 2017.
- [6] Yuan F., Xiaobin W., and Shulu Z., Failure Modes of Masonry Infill Walls and Influence on RC Frame Structure Under an Earthquake, Tenth U.S. National Conference on Earthquake Engineering, *Frontiers of Earthquake Engineering*, 2014, Alaska.
- [7] Maidiawati, Sanada Y., Konishi D. and Tanjung J., Seismic Performance of Nonstructural Brick Walls Used in Indonesian R/C Buildings, *Journal of Asian Architecture and Building Engineering (JAABE)* Vol 10 No 1, 2011, pp. 203-210.
- [8] Tanjung J. and Maidiawati, Experimental Study on the Effect of Brick Masonry Walls on the Lateral Strength of the Reinforced Concrete Structures (in Indonesian), *Jurnal Teknik Sipil ITB*, Vol 23 No 2, 2016, pp. 99-106.
- [9] Tanjung J. and Maidiawati, The Experimental Investigation on Beneficial Effects of the Local Brick Masonry Infills to Seismic Performance of R/C Frame Structures in West Sumatera, *International Journal of Civil Engineering and Technology (IJCIET)*, Vol 8, Issue 10, 2017, pp. 687-697.
- [10] Al-Chaar G., Evaluating Strength and Stiffness of Unreinforced Masonry Infill Structures, Research Report ERDC/CERL TR-02-1, U.S. Army Corps of Engineers, 2002.
- [11] Cavaleri L., Di Trapani F., Cyclic response of masonry infilled RC frames: Experimental results and simplified modeling, *Soil Dynamics and Earthquake Engineering*, Vol. 65, 2014, pp. 224-242.
- [12] Korkmaz H.H. and Taciroglu E., Experimental Investigation of Contribution of Brick Infill Walls to the Seismic Response of Reinforced Concrete Frames, *Proc. Of Int. Conf. on Structural Arch. and Civil Eng.*, Dubai, 2015, pp. 222-227.
- [13] Maidiawati and Sanada Y., R/C Frame–infill Interaction Model and Its Application to Indonesian Buildings, *Earthquake Engineering & Structural Dynamic*, Vol 46, 2017, pp. 221–241.
- [14] Pradhan P.M., Pradhan P.L, and Maskey R.K., Lateral Strength of Partial Masonry Infill Wall in Concrete Frame Under Static Load, *Journal of Civil Engineering (IEB)*, Vol 40 (1), 2012, pp. 67-77.
- [15] Kakaletsis D.J., Masonry Infills with Window Openings and Influence on Reinforced Concrete Frame Constructions, *Earthquake Resistant Engineering Structures VII*, WIT Press, 2009, pp. 445-455.
- [16] Surendran S. and Kaushik H.B., Masonry Infill RC Frames with Openings: Review of In-plane Lateral Load Behaviour and Modeling Approaches, *The Open Construction and Building Technology Journal*, Vol 6 (Suppl 1-M9), 2012, pp. 126-154.
- [17] Akhoundi F., Lourenço P.B. and Vasconcelos G., Numerically Based Proposals for the Stiffness and Strength of Masonry Infills with Openings in Reinforced Concrete Frames, *Earthquake Engineering & Structural Dynamics*, Vol. 45, Issue 16, 2016, pp. 869-891.
- [18] Interim Testing Protocols for Determining the Seismic Performance Characteristic of Structural and Nonstructural Component,” FEMA 461, 2007, pp. 21-25.